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Vanadium Steels

**Their Classification
and Heat Treatment
with Directions for
the Application of
Vanadium to Steel
and Iron**

American Vanadium Company
Pittsburgh, Pennsylvania



Class TN 737

Book V3A6

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1911

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THEIR Classification and
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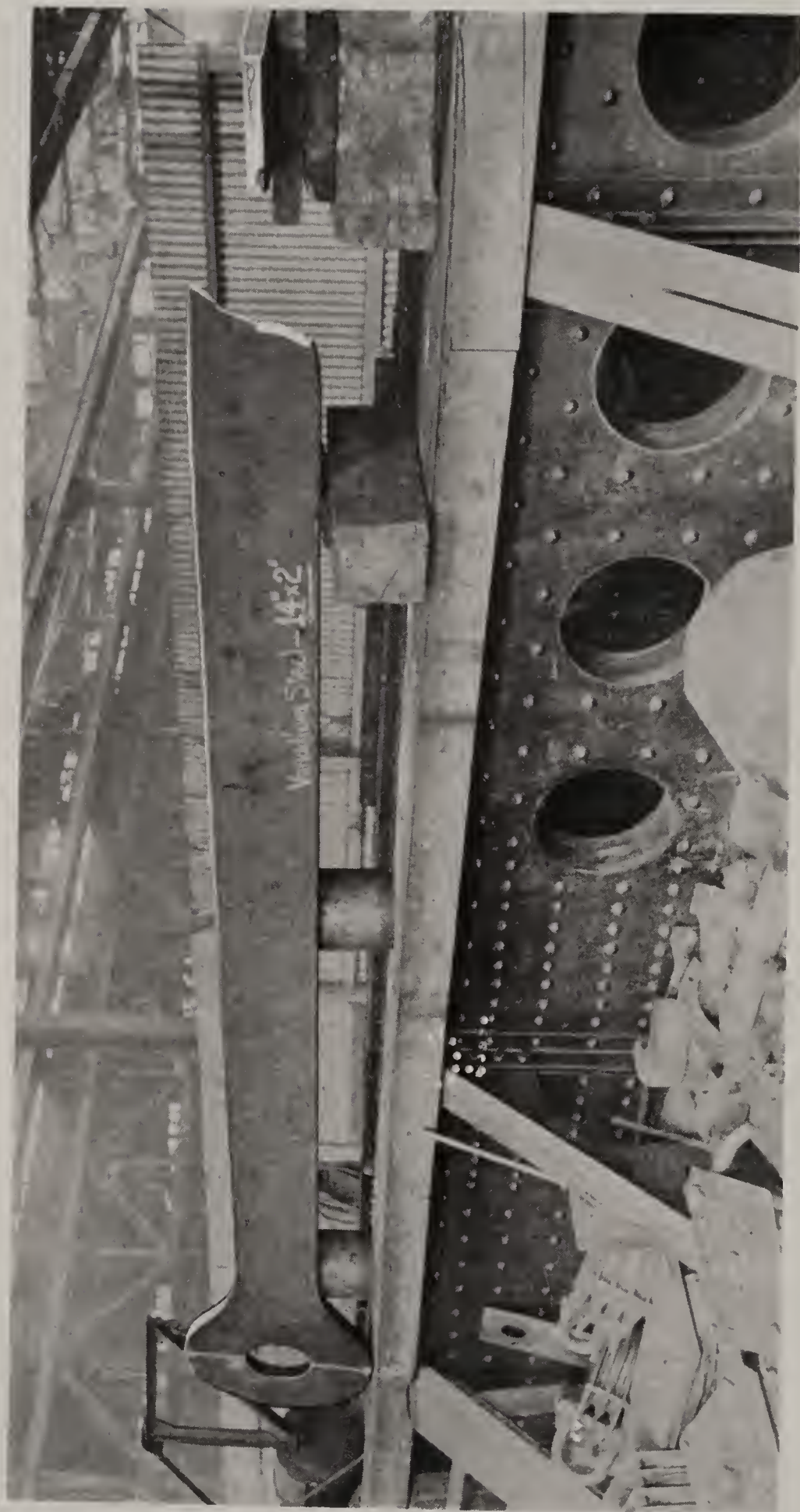
IT HOLDS THEM ALL TOGETHER.

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Destruction test on full-sized Eye Bar of Vanadium Steel
Elastic Limit 80,840 lbs. per square inch. Tensile Strength 99,890 lbs. per sq. inch.
Elongation in 12 inches, 32.5%. Elongation in 20 feet, 7.9%. Reduction at fracture, 52.3%. Fracture, silky.

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HISTORICAL

THE element Vanadium has, within the past few years, sprung from the position of a scientific curiosity to that of a commercial metal which, suitably applied, has marked an epoch in the history of the steel trade.

The existence of the element was first recognized in 1801 by Del Rio, professor of mineralogy in the city of Mexico. He found it in a brown-red ore from Zimapan, and after noting that it was different from chromium and uranium, called it erythronium because of the red color of its salts. In May, 1803, there is an obvious reference to the new metal under the name of panchrome.

Contemporaneous chemists discredited the observations of Del Rio. Humboldt and Bompland sent samples of his newly discovered ores to France where they were submitted to Collet-Descotils for analysis. Before the results were published, Del Rio had renounced his own discovery and concluded that he had found only a basic chromate of lead. Collet-Descotils too hastily confirmed this assumption by stating that no new element was contained.

The matter rested here for about thirty years when Sefström discovered a substance similar to erythronium in a piece of soft iron remarkable for its ductility and made from the magnetic ores of Taberg, Sweden. He succeeded in studying its characteristic reactions and in marking the distinctions between it and chromium as well as uranium, both of which metals exhibited many analogies. With only two decigrams of material to work upon he established the existence of the new element beyond question, recognized its several degrees of oxidation and even described some of its salts. He proved that it was identical with the discredited erythronium of Del Rio but gave it the more euphonious name of Vanadium, after the goddess, Vanadis, one of the Scandinavian Valkyries.

The element was not isolated as a metal until 1867, when Sir Henry Roscoe made a study of its compounds and indicated its use, necessarily to a small extent, in dyeing, tinting glass, coloring porcelain, etc.

Pure Vanadium is silvery-white in appearance and melts only in the intense heat of the electric furnace. It has, in the pure state, but an academic value.

Its atomic weight is 51.27; its specific gravity at 15° C. is 5.5, and its specific heat is 0.1233 at 0° C.

Sefström was the first to notice the presence of Vanadium in Swedish irons and steels of the very highest quality, and this seemed to indicate its application for the specific purpose of improving iron and steel by the deliberate addition of the new element.

It was observed that an alloy of Vanadium and iron in the respective proportions of one to two had a comparatively low melting point and that the judicious use of the element in small quantities conferred marvelous properties to steel.

An application having been indicated, it was next essential to secure a supply. Until very recently Vanadium has been classed as a rare element and as late as 1895 its price was estimated at more than \$10,000 a pound. It is, however, a very widely scattered metal and a sufficiently searching analysis will indicate it in almost every kind of soap, in ordinary pottery, in many types of lead and silver ores, in some of the bituminous coals of South America, in the copper deposits of the Lake Superior region, in the porcelain clays of France, in Bauxite, and in association with titanium ores. Though widely distributed, the percentages of Vanadium are usually very minute and the commercialization of the element was made possible only by the discoveries of the engineers of the American Vanadium Company, who located an unusually rich mine almost 16,000 feet above sea level in the mountains of Peru.

After years of experiment and the expenditure of very large sums of money by this company, Vanadium products are now available at satisfactory prices in any quantity.

Owing to its discovery in sufficient amounts to make its remarkable properties available in the metallurgical field, not only for steel, but for iron, copper, brass, bronze and aluminum, Vanadium has been brought down from a value many times that of gold to a price that permits its use in tool steels, forgings, bridge members, automobile parts, steel castings, and in general, in all types of metal that are required to yield the highest class of services.

Vanadium Steels meet the requirements which the best classes of ordinary steels are unable to satisfy, and which the highest classes of previously known steels of the most expensive character were unable to meet.

Ferro-Vanadium is the alloy by means of which Vanadium is introduced into steel and iron; Cupro-Vanadium is used with copper, brass and bronze, and Alumino-Vanadium with aluminum.

The first experiments with Vanadium in steel were not uniformly good, because the Ferro-Vanadium employed contained carbon or other elements that destroyed the beneficial action of the Vanadium.

In the manufacture of Vanadium Alloys for any class of metallurgical work, it is of vital importance that injurious elements shall be completely eliminated. The factory of the American Vanadium Company is the largest of its kind in the world, and the only one that produces Vanadium Alloys in commercial quantities on a guaranteed analysis and free from harmful impurities.

With Vanadium Alloys scrupulously true to specifications, and with a knowledge of the proper modes of heat treatment, the metallurgist of today has at his command materials of construction immensely superior to any previously known, and is able to move into lines of accomplishment with perfectly adequate means for every requirement.

Useful Strength in Steel

It had been the custom for many years to form an opinion of the qualities of steel by its behavior when subjected to a steady load or a slowly applied bending action, that being considered the best metal which was strong and ductile, stretching greatly before breaking under a steady pull, and bending without breaking. Ductility could be maintained in steels of ordinary composition up to a certain strength, but beyond this the metal became brittle.

Steels were next prepared in which much higher resistance to load could be attained before brittleness was reached, through the use of various alloys. But it soon became apparent that in many cases the ductility thus attained did not necessarily imply a certainty that the metal would behave well under stresses applied in a different manner. Statically ductile steel fractured sometimes like glass under the influence of shock, whether so severe as to be termed "overwhelming" in nature, or much lighter and continually repeated, or even under the influence of constant vibration.

The needs of the engineer of today demand, with increasing force, strong steel which shall be enduring under such conditions as the latter, and it has become obvious that the same basis of judgment should not be taken literally in indicating the suitability of materials for such widely different purposes as—to take two typical examples—the manufacture of (1) bridges and (2) locomotive connecting rods.

In modern machine construction, especially in those parts which are liable to failure in service, *it is, after all, "dynamic" superiority that is the essential consideration*, namely, resistance to repeated stresses, to alternating stresses, to simple or repeated alternating impacts and to fatigue (which latter is the outward visible sign of molecular disintegration). Thus a new field has been opened out and in this field Vanadium was found by extended experiment and prolonged practical experience to be pre-eminent, in fact to stand alone.

Vanadium statically intensifies tremendously the strengthening power of other ingredients, enabling such a small quantity of that ingredient to be used as not to injure the metal dynamically; in itself, it confers remarkable dynamic

properties to steel; it retards "segregation," and so renders steel particularly susceptible to the highly important improvements due to tempering; utilizing this same characteristic, steels can be prepared which are very resistant to wear and erosion; Vanadium toughens steel, and confers to it great powers of resistance to torsional rupture; in a word, it endows it with the quality of "life" in practical work.

"Dynamic" Testing of Steel

In the table on pages 32 and 33, the dynamic figures shown under the heading of "alternations" were obtained by means of the alternating impact test performed on the Landgraf-Turner machine under strictly standard conditions.

In this form of test, the test piece, held securely at one end in a vise, is moved backwards and forwards by means of a slotted arm which communicates to the piece successive permanent distortions in each direction, such distortions having been produced by means of an impact followed immediately by a pushing motion. As a result, the test piece is fractured finally on the line of the vise, at which point the severest stresses are created. The slotted arm moves on a crank, so that the pushing motion is performed without the interfering factor of "rub," as the slotted arm describes the same arc as the distorted test piece.

It has been objected by some engineers that, as in commercial work they never anticipate the stresses on metal parts to even approach the elastic limit of the metal, this test has no bearing on service conditions. On the other hand, it is universally conceded that the great majority of service fractures are caused by strains which are repeatedly applied, thus resulting in the molecular deterioration of the metal. Furthermore, it is allowed that the nearer such repeated stresses individually approach in degree the elastic limit, the more rapidly the rate of deterioration is increased. Hence, by submitting a metal to rotary vibration against an overhanging weight, unless the fibre stress thus communicated in each case bears a strict relation to the elastic limit of the metal under investigation, the figures obtained are so obscured as to render the results valueless for purposes of

comparison. In addition, many other factors influence the results of a rotary test, such as fluctuation in the rate of rotation, "whipping" of the sample, deviation from true alignment, swinging motion of the overhanging weight, and the method of the initial application of the same, all of which tend further to render the results of the test non-comparable.

The function of the alternating impact test is to rapidly tear apart, both from each other and in themselves, the constituent "crystals" of the metal of the test piece; and as a result, the inherent value of the metal, in resisting molecular deterioration, is obtained. Thus, although the alternating impact test would at first sight appear to have nothing in common with practical conditions, the identical results required for successful service performance are obtained. Without elaborating further on this matter, it will be sufficient to refer any interested persons to the prolific work of Professor Arnold, Professor MacWilliam, Mr. J. T. Milton, Mr. W. L. Turner and many others, on the service value of the test.

It has already been said that the rate of deterioration advances enormously as the conditions are more drastic, and therefore direct readings of the alternation machine should be taken in some measure of geometrical proportion, rather than in arithmetical proportion, in deducing "life" value, as a progressive or detailed fracture is produced in the course of a couple of minutes on the testing machine in question.

Effect of Vanadium

Vanadium steels of numerous types are being made regularly by the progressive steel mills of the world and the properties of the steels obtained fully substantiate the published tests.

Vanadium exerts its power in at least three ways:

1. It *indirectly* toughens steel, owing to its scavenging action, by removing oxides, nitrides, etc., in a fusible form easily carried away in the slag. In this respect, it differs from some other deoxidizing alloys.

2. It *directly* toughens steel mainly by its solid solution, under normal conditions, in the carbonless portion known as ferrite. To succeed in this respect, the alloy must either contain free Vanadium, or Vanadium combined with some other element which also goes into solid solution in ferrite under normal conditions, such as silicon.

3. It forms complex carbides of such nature as to statically strengthen the steel containing them. These carbides are proved to add more strength to steel when they contain chromium or nickel.

Heat-Treatment of Vanadium Steel

The term “heat-treatment” is of comparatively recent origin. Strictly, however, it covers processes which have been practiced for many years, namely

Annealing, and
Tempering.

The extension of the term to include such manipulation by heat as will either wholly or partially restore a steel which, owing to mechanical, thermal, or service conditions, has become dangerously crystalline and brittle—a question full of controversy at the moment—should not really enter into the heat-treatment of newly-made or of unused steels.

Before dwelling on the commercial phase of the subject, the ultimate structure of a piece of constructional (or “sub-saturated”) steel, under normal conditions, will be considered in as elementary and non-technical manner as possible. Such steel consists primarily of iron, with more or less carbon, some sulphur, phosphorus and manganese, and possibly, silicon, nickel, chromium or Vanadium, in addition.

The carbon therein contained is combined chemically with a molecular proportion of iron. A molecule of this chemical compound alloys itself with twenty-one atoms of carbonless iron and the resultant alloy is distributed in mesh form, through the main background or network of carbonless iron. This alloy is known technically as pearlite, and the free carbonless iron as ferrite. The precise manner in which this pearlite is arranged in respect to size, plate-

like form, regular or irregular distribution, etc., depends to a considerable degree on the nature and amount of "hot work" put on the steel, the rate of cooling, and so on.

Manganese is found as a constituent of the pearlite; a part of the manganese unites chemically with the sulphur (also possibly with some of the silicon) of the steel, the resultant compound forming striae, or globules throughout the mass.

The phosphorus and the remainder of the silicon, and, if used, a large part of the nickel, are dissolved in the ferrite, in the form known as "solid solution."

Chromium is found as a constituent of the pearlite.

Vanadium is found partly in solid solution in the ferrite (free and constituent in the pearlite), which it toughens, and partly in the carbide portion of the pearlite, which it strengthens.

If heat be applied to a bar of normal steel, it will become sensibly hotter with each successive increment of heat up to a given point. Thereupon further application of heat causes a molecular rearrangement instead of increasing the sensible temperature of the steel; the pearlite becomes broken up, its carbides going into solid solution in the ferrite. When such decomposition and solution are complete, sensible temperature of the steel again rises as heat is applied.

In cooling the steel, the converse takes place. To a certain point, the steel cools regularly; then it apparently ceases to cool, its dissolved carbides being thrown out of solution, and alloying themselves with ferrite to re-form pearlite. When the carbides are completely thrown out of solution, sensible cooling again regularly proceeds.

Such is a brief explanation of the phenomena of calescence and recalescence.

The object of annealing is to break up the carbide areas and distribute the same in small colonies. Wherefore, the steel should be heated above the calescence point, this temperature being maintained long enough to thoroughly decompose the pearlite, as well as to remove any strains that may have been locked up in the mass during mechanical operations; it should then be allowed to cool slowly through the

recalescence point, due precautions being taken to prevent chilling, etc. The less plate-like the formation of the pearlite thus reformed, and the more granular (or "sorbitic") the colonized carbide areas, the better the annealing.

The general appearance of pearlite in worked, but un-annealed steel will be seen in microphotograph No. 1 (the white portion of the photograph represents carbonless iron, or ferrite), while the result of excellent annealing of such steel will be seen in microphotograph No 2, page 22.

A Vanadium ferrite does not permit of the ready passage through it of the carbides precipitated at the recalescence point; therefore the colonization of carbides in such steel is much less complete and their distribution better; consequently, the toughness and tenacity of the steel is increased, irrespective of the added toughness of the background of Vanadium ferrite. Exemplification of this is shown in microphotograph No. 3, page 22.

If the steel heated above its calescence point (when it contains all its carbides in solid solution), be subjected to very quick cooling, so that no chance is given for the deposition or reprecipitation of its dissolved carbide, a new body is formed, known by the generic term "martensite;" in other words, martensite may be said to consist of a frozen solution of carbides in ferrite. In its nature, this body is brittle and intensely hard. The intensity of its hardness, however, naturally varies both with regard to the nature and amount of carbides contained in the frozen solid solution, and to their rate of freezing.

For most machinery purposes, it is better to make this sudden abstraction of heat by quenching in an oil bath. Quenching in water certainly results in the quicker abstraction of heat and in the formation of a more intense martensite, but water quenching is very apt to give rise to the formation of small (they may be microscopically small) cracks, which militate severely against the useful performance in service of the steel which has undergone this process of quenching.

Under certain conditions, oil may be replaced, with more or less advantage, by different aqueous solutions; this course

is resorted to when it is desired to impart a more intense hardness to the material than can be attained by quenching in oil and at the same time to avoid the formation of the minute cracks due to ordinary water-quenching.

In passing, it should be noted that steels containing considerable quantities of chromium and manganese together are particularly liable to give rise to cracks when quenched in water.

The typical martensitic structure obtained by quenching Type "A" Chrome-Vanadium steel in oil from 900° C., is illustrated in microphotograph No. 4, page 22.

Martensite is not a stable "body," its equilibrium being destroyed very much below the calescence point; when subjected to a temperature of about 360° C., for a period of time sufficient to thoroughly soak through the mass, it is decomposed, its carbides being deposited *in situ* and soft ferrite liberated as a background. As the temperature applied in this tempering (or "letting down") heat is increased, the carbides begin to flock together, the rate increasing much more rapidly as the tempering heat is augmented.

Microphotograph No. 5, page 23, illustrates the tempering of the steel shown in microphotograph No. 4, by the immersion at 550° C., for fifteen minutes, of a 1¼-inch round bar.

Microphotograph No. 6, page 23, shows the grouping together of the carbides on increasing the temperature, this being precisely the same steel as shown in microphotographs Nos. 4 and 5, except that the tempering heat was continued to 630° C.

At the calescence point the deposited carbides once more go into solid solution, and are again precipitated on cooling the steel; if such cooling be slow, the phenomena of an annealed steel are obtained. Hence, it will be seen, that the oil tempering operation, which consists essentially of the two processes of quenching and of letting down (or drawing back), must be practiced so that the letting down is never performed at or above the calescence point, otherwise the virtues due to the oil tempering are entirely lost.

It would be well to observe in connection with this drawing back, or letting down, process, that it can be accomplished excellently at low temperatures in an oil bath kept at the requisite temperature by means of a fire or gas burner.

An excellent way of drawing back small quenched articles, which are required to be let down at a higher temperature than is consistent with the use of hot oil, is to immerse same in a bath of molten lead, or fused salts, kept at the desired heat by means of a fire.

Drawing back may also be accomplished, for both large and small articles, by placing them in a furnace which is *already at the desired temperature, maintaining such heat during the prescribed period*. The recalescence points of similar steels, made by the different processes hereinbefore mentioned, being substantially the same, the annealing treatment recommended is applicable in all cases. When it comes to temper, however, three facts must be considered:

1. That the stiffer steels when quenched form more intense martensites.
2. That some quenching liquids are more drastic than others.
3. That the more intense the martensite, the more decomposing it takes, other things being equal.

In the treatments hereinafter recommended, the figures given are with respect to quenching in lard oil, or a mixture of lard and fish oils, which mixture will be found very satisfactory.

The oil is generally contained in a tank which is water-cooled, so that the temperature of the bath is usually about 50 or 60° C., or in some cases, possibly a little higher. It is not absolutely necessary that lard and fish oils be used alone, as it is admissable to add a considerable quantity of cotton seed oil, etc., but the characteristics of such mixture of lard and fish oils should be adhered to as much as possible; for example, the admixture of any class of medium-thin paraffin oil would not be recommended.

A more drastic quenching liquid than the above, would be cold water, which, however, for reasons already explained,

is not recommended for structural steels, while iced brine and quicksilver are still more drastic in their cooling action. Even in the case of cold water, the temperature from which the steel is quenched must be about 50°C. to 150°C. less (always keeping it above the calescence point, of course) than if the quenching were done in oil, in order to obtain the same degree of martensitic formation.

It is apparent that if absolutely the same composition be followed irrespective of the process of manufacture, as the stiffer steels form martensites which require more breaking up, the drawing back temperatures in tempering should be correspondingly somewhat higher, or the quenching temperatures somewhat lower, or both, so that the final results may in each case be equal. Similar remarks apply if two steels be made by the same process, one of which is somewhat stiffer than the other, owing to composition.

Conversely, if quenching and drawing-back temperatures are kept constant, then the figures on the table which apply to the composition of basic open-hearth steels must be modified somewhat in their stiffening elements, according to the process of manufacture, so that the final results be the same.

Such modifications in composition are approximately given in tabular form.

The stiffening elements may be said to be carbon, manganese, chromium, and part of the Vanadium. It is assumed that the phosphorus and sulphur, the former especially, remain reasonably low in every case.

Taking an example: If acid Type "D" Chrome-Vanadium spring steel be made, and is to be subjected to the heat-treatment indicated in the table, the carbon should be kept in the neighborhood of .45%, the chromium should be kept down to but little over 1%, while the manganese content should be about .80%. If on the other hand, the Type "D" composition shown on the table for basic open-hearth steel be used in the case of acid steel, the quenching in oil of the resultant spring bar should be done from a temperature of about 850°C. and the drawing-back performed between 450°C. and 550°C.

All steels to be as free as possible from sulphur and phosphorus. The sulphur percentage may go to .04% without detriment.

In these compositions the Vanadium given in each case is that which should be *contained* in the steel.

From the earlier remarks it will be seen that an extra amount of Vanadium must be *added* in order to compensate for that lost in combination with oxides and nitrides.

Under normal conditions of good melting, it would be safe to assume that the finished metal in the furnace would contain rather less than .01% of nitrogen and about .02% of oxygen. To provide for this amount of nitrogen and oxygen, about .07% of Vanadium (reckoned on the weight of the steel) would be required by open-hearth steel which has been well deoxidized by ordinary means.

In a steel of ideal properties it is a certainty that composition must play the leading "rôle," for though it is possible to manipulate a steel of bad composition so that it fulfills a few of the requirements of a good steel, it is impossible by simple (or complex) "faking"—to use the term of Professor Arnold in this connection—to attain them all. Given the necessary composition, both the processes of manufacture and the treatment of the product must be carefully carried out to ensure success, and in a steel of new composition these may deviate somewhat from routine practice as applied to ordinary steel. Hence something further is required after the matter of composition is settled.

Range of Chemical Compositions

for the various types of Vanadium Steel,

as recommended by the American Vanadium Company

These compositions are approximately what steel makers are furnishing in the various types of Vanadium steel, though many modifications are currently used. *In ordering steel, the purpose for which it is to be used and the physical properties desired should always be given.*

	MILD	REGULAR	FULL
TYPE "A"			
Carbon-----	.18% to .25%	.25% to .32%	.32% to .37%
Manganese-----	.35% to .50%	.40% to .60%	.40% to .50%
Chromium-----	.60% to .80%	.80% to 1.00%	.80% to 1.00%
Silicon-----	under .20%	under .20%	under .20%
Vanadium-----	over .16%	over .16%	over .16%
TYPE "D"			
Carbon-----	.35% to .43%	.43% to .52%	.52% to .60%
Manganese-----	.70% to .90%	.70% to .90%	.60% to .80%
Chromium-----	.80% to 1.10%	.80% to 1.10%	.80% to 1.10%
Silicon-----	under .20%	under .20%	under .20%
Vanadium-----	over .16%	over .16%	over .16%
TYPE "E"			
Carbon-----	-----	.10% to .15%	.15% to .20%
Manganese-----	-----	.25% to .40%	.25% to .40%
Chromium-----	-----	.25% to .40%	.25% to .40%
Silicon-----	-----	under .20%	under .20%
Vanadium-----	-----	over .12%	over .12%
TYPE "F"			
Carbon-----	-----	.08% to .14%	-----
Manganese-----	-----	.20% to .30%	-----
Silicon-----	-----	over .10%	-----
Vanadium-----	-----	over .10%	-----

Chemical Compositions—Continued

	MILD	REGULAR	FULL
TYPE "G"			
Carbon		.55% to .65%	
Manganese		.60% to .80%	
Chromium		.80% to 1.00%	
Silicon		.20% to .30%	
Vanadium		over .16%	
TYPE "H"*			
Carbon		.75% to .85%	.85% to 1.00%
Manganese		.30% to .45%	.30% to .45%
Chromium		.80% to 1.00%	.45% to .60%
Silicon		under .20%	under .20%
Vanadium		over .16%	over .16%
TYPE "J"			SPECIAL
Carbon		.20% to .35%	.40% to .50%
Manganese		.50% to .80%	.50% to .80%
Silicon		.20% to .35%	.20% to .35%
Vanadium		over .16%	over .16%
TYPE "K"			REGULAR
Carbon		.45% to .55%	
Manganese		.30% to .45%	
Chromium		.80% to 1.10%	
Silicon		under .20%	
Vanadium		over .16%	

NOTE: Sulphur and phosphorus to be below .04% for all types excepting Type "J" and "J" Special, in which cases they can be as high as .05%. The figures given for Vanadium are contained Vanadium. See pages 15 and 56.

*Type "H" is specially intended for cutter work and would be modified, mainly as to its carbon percentage, in order to make it suitable for other work, such as saws, etc., while in some cases its manganese content would be also lowered.

Heat Treatments

Based on Compositions given on pages 16 and 17.

No. 1. Anneal at 800°C . for one or two hours, cooling slowly in air, in ashes, or even in the furnace, according to the nature of the piece, the cooling process being made to take place more slowly with smaller pieces, as such small pieces do not contain any body of heat.

No. 2. Quench from 900°C . in oil and anneal ("let down" or "draw back") the quenched piece at 550°C . for one-half to two hours, according to size of piece. Cool in air.

No. 3. Quench from 900 to 950°C . in oil and anneal at 360°C . for one-quarter to one-half hour. Cool in air.

No. 4. Quench from 875°C . in oil and draw back at 400 to 450°C . Cool in air.

No. 5. Quench from 850°C . and draw back at 550°C . Cool in air.

No. 6. This number represents the special tool tempering treatment which is applied in ordinary circumstances to the nature of the same tool when made from ordinary steel.

No. 7. CASE HARDENING PROCESS: The essential feature of casehardening involves not only the production of a body having a hard outside, but of one which at the same time has a strong and tough core. Thus it will be seen that no tempering steel should be casehardened, for as the practically final process of casehardening involves a quenching treatment, such steel would become hard right through. Taking advantage of the comparatively slow transition of carbides through a Vanadium ferrite, and of the strong nature of Vanadium ferrite interspersed with well emulsified Vanadium sorbite, and further of the comparatively tough nature of Vanadium martensite, the type "E" Chrome-Vanadium steel is particularly suited to the casehardening process. The raw steel is essentially a mild steel and is illustrated in microphotograph No. 7, page 23, while a piece cut from the core of the cased and quenched article made from this steel is structurally illustrated in microphotograph No. 8, page 23. The strong similarity of microphotographs No. 6 and 8 show that by quenching this type "E" steel a physical result is

obtained which is almost exactly comparable with slightly over-tempered type "A" Chrome-Vanadium steel, and this similarity is further evidenced by the results of many tests made in the mechanical laboratory.

The best casehardening process will be found by proceeding on the following lines:

The rough machined material is annealed, *irrespective of its softness*, in order to remove all strains imprisoned therein through the mechanical processes of forging or rolling. This is a very important item, as the first time the article is subjected to sufficient heat, these strains are liberated, and distortion ensues; consequently, if the piece has already been machined to dead size and the strains are liberated by means of the casing heat, the quenching process fixes this distortion permanently. After such annealing, the article is machined to finished size and is packed in the carburizing material. Many good carburizing materials are to be found: bone, bone-dust, hydro-carbonated bone, good charred leather, and a mixture of charcoal and carbonate of baryta all being suitable. Great things are claimed for the last named, especially in France, on account of its declared regularity of penetration, but it would seem that its use is principally in the direction of the cementing of large articles, such as plates, etc. It is the consensus of opinion that the best carburizing agents are nitrogenous; nitrogen compounds probably assist the carburizing either by the promotion of secondary reactions, or as some contend, through their lowering action on the transformation point of iron. Small amounts of nitrogen, pure and simple, are absorbed or occluded from them by the iron to be cased, but such nitrogen is expelled by the reheating preceding quenching. It is important that the carburizing material should be thoroughly dried, evenly sized and free from all admixture of earthy or metallic impurities. The luting of the box containing the packed articles should be done with *clay which is absolutely free from grease*. The box and its contents are then heated to 1000° C. and kept there as long as may be necessary; it is impossible to *fix* any given time, as naturally this must be regulated from practical experience, taking into consideration the contour of the article to be cased, its size, and the depth of casing desired.

The box and its contents are allowed to cool, the articles removed, brushed and reheated in an atmosphere as non-oxidizing as possible, to 850° C., when they are plunged in clean, cool water. The article thus quenched is thrown into hot oil and kept at a temperature of about 200° C. to 250° C. for some time in order to release some of the strains caused by quenching. This oil warming does not appreciably interfere with the surface hardness of casehardened machinery steels, but it relieves imprisoned strains very considerably.

Trials made on test bars of open-hearth basic steel of the type above shown gave the following typical figures—in the soft condition:

Elastic limit, pounds per square inch	40,000
Tensile strength, pounds per square inch ...	60,000
Elongation in 2 inches	35%
Reduction of area	65%

Bars of 1⅛ and 1¼-inch diameter were cleaned and cased as recommended. The casehardened bars were subjected to load until the outer surface was cracked; the bars had then taken a very appreciable bend, although the casehardening had penetrated at least one millimeter. The bars were then broken; sharp corners of the case would easily scratch glass. The hard casing was next ground away and as soon as a portion was obtained sufficiently soft to be machined, were turned down to the ordinary shaped tensile test-piece, and also to round rods about one-half inch diameter. Tensile test of the actual cores showed the following figures:

Elastic limit, pounds per square inch	70,000
Tensile strength, pounds per square inch ...	97,000
Elongation in 2 inches	21%
Reduction of area	62%

In each case the machined half-inch rounds from the core bent double cold.

Other bars were deeply cased and a photograph (three times natural size) of such a bar, fractured, is shown on page 40.

Rounds were also casehardened and were beaten out cold to rectangular shape. The casing, although shattered, adhered to the soft core. The photograph on page 41 (three times natural size) shows a piece treated in this way.

The dynamic figure under alternating impact was exceptionally high when the steel was in the soft condition; quality figures deduced from the static tests and the alternating impact tests on the Turner formula gave the high quality figure of approximately 6000, while the "core" gave a correspondingly high quality figure.

In the foregoing, all temperatures quoted were determined by the electric pyrometer. The appended table gives the approximate color valuations of these temperatures in the diffused daylight of the ordinary shop. The temperatures generally enunciated in the pocketbooks as corresponding to various color shades should on no account be taken, as they are based on the falacy that the specific heat of iron is constant for all temperatures, which is now known to be a grossly mistaken view.

Approximate Correlation of Color Temperature

As Viewed in the Diffused Daylight of the Ordinary Shop, with
the Reading of the Electric Resistance Pyrometer

Black red (just visible)	About 500°C
Dull blood red	" 550°C
Warm blood red	" 600°C
Cherry red	" 700°C
Very full cherry red	" 800°C
Light red, merging from very clear cherry	850 to 900°C
Orange to light yellow	1000 to 1100°C
White	1200°C
Throwing off sparks, i.e., scintillating heat of fairly mild steel	" 1300°C
(Melting point of mild steel	" 1520°C
(Not determined by electric resistance.	

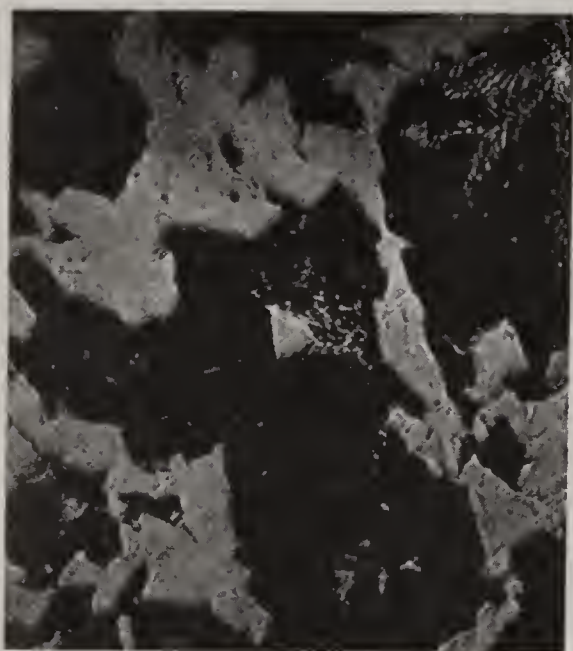


Fig. 1

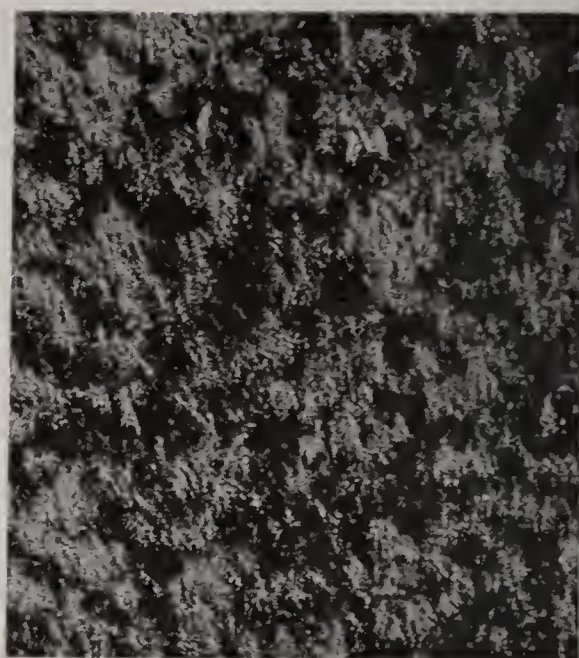


Fig. 3

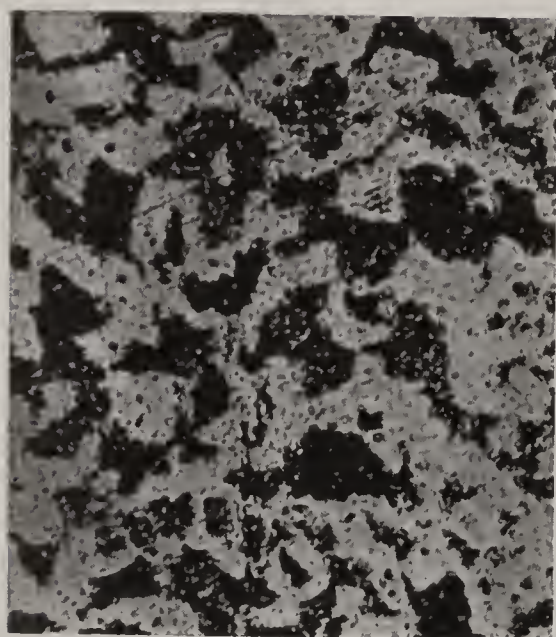


Fig. 2



Fig. 4

PLATE 1. All microphotographs from etched transverse sections, vertically illuminated and magnified 360 diameters

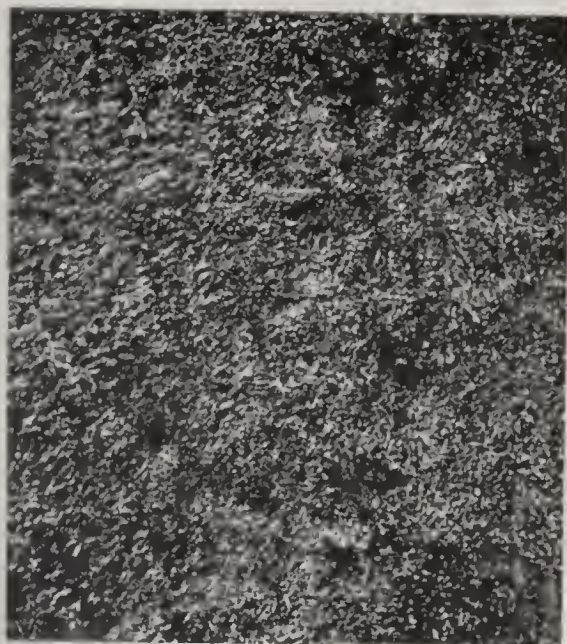


Fig. 5

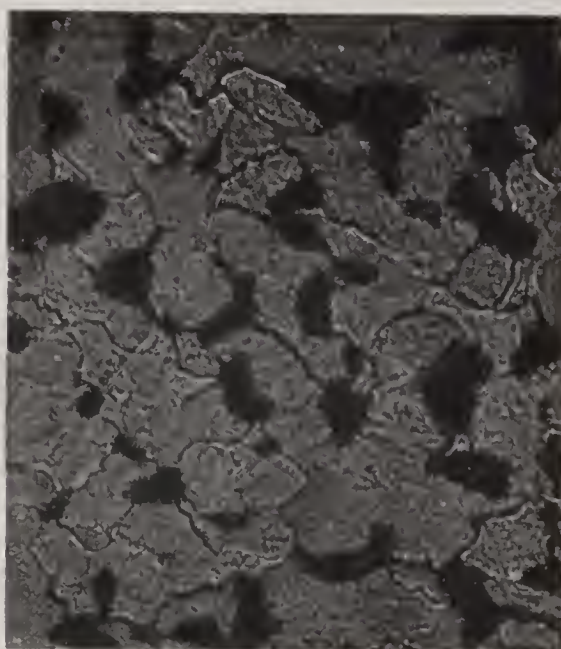


Fig. 7

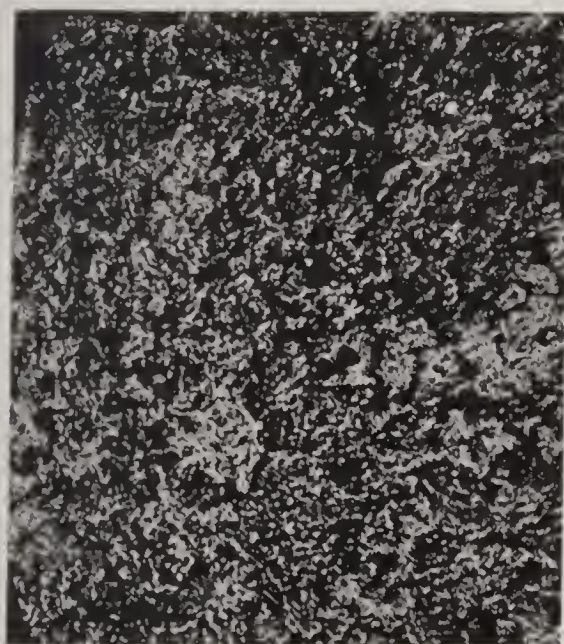


Fig. 6



Fig. 8

PLATE 2. All microphotographs from etched transverse sections, vertically illuminated and magnified 360 diameters

Some Applications of Vanadium Steel, and the Type and Treatment Recommended for each case

There is no single type of Vanadium steel that does all things. It is necessary to make various kinds and grades for different purposes, and below is found a list of the purposes for which different Vanadium steels have been successfully applied, with instructions as to their proper heat treatment to meet specified requirements.

In the tables presented, with regard to composition and heat treatment, the results have been *mainly* deduced from experience with basic open-hearth Chrome-Vanadium steels and are corroborated by service records and by exhaustive microscopic investigation.

	TYPE	HEAT TREATMENT NO.
A		
Air Reservoirs	A	2
Ammunition Hoists	A	
Ammunition Wagons	A	
Anchors	F	Normal
Angles	A, E	"
Armature Shafts	A	2
Armor Plate	Special	
Armor Plate Bolts	A	1 and 2
Automobile Boiler Tubes	E	Annealed
Automobile Castings	J	Annealed
Automobile Forgings	A, D, E	1, 2, 5 and 7
Axes	H	6
Axes—Automobile	A	2
Axes—Electric Car	A	2
Axes—Field Gun Carriage	A	2
Axes—Freight Car	A	2
Axes—"Light"	A	2
Axes—Locomotive	A	2
Axes—Passenger Car	A	2
Axes—Tender Truck	A	2

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
B		
Ball Mill Plates	H	6
Ball Mill Shafts	A	2
Bars	All types	
Beams	A, E	Normal
Bicycle Chains (part)	A	2
Bicycle Tubes	A, E	1 and 2
Billets	All types	
Blooms	All types	
Bolts	A, E	1 and 2
Bridge Pins	A, D	2
Bulb Angles	A, E	Normal
Ball Races	E, H	7 and 6
C		
Cables, Wire	A, D	1 and 2
Cam Shafts	E	7
Channels	A, E	Normal
Columns, Rolled	A, E	"
Condenser Tubes	E, F	1, Normal
Couplers	J	Annealed
Crank Pins	A, D	2
Crank Shafts	A	2
Crank Webs	A	1 and 2
Cross Heads (Locomotive)	J	Annealed
Cutlery	H	6
Casehardening Steel	E	
CASTINGS		
Automobile Castings	J	Annealed
Couplers	J	"
Crank Webs	J	"
Cylinders	J	"
Dredge Bucket Lips	Special	"
Frogs and Switches	Special	"
Gearing and Gear Wheel Blanks	Special	"
Knuckles	Special	"
Rolling Mill Pinions	J Special	"
Rolling Mill Rolls	J	"

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
LOCOMOTIVE CASTINGS		
Air Brake Cylinder Levers	J	Annealed
Bell Cranks		
Brake Beams		
Brake Brackets		
Boiler Pads		
Buffers		
Cross Heads		
Cross Head Shoes		
Cross Head Arms		
Cross Braces		
Cab Brackets		
Cylinders and Heads		
Centre Plates		
Driver Brake Levers		
Driving Boxes		
Driving Box Beams		
Driving Wheel Centres		
Draw Heads		
Engine Frames		
Engine Truck Frames		
Engine Truck Centre Pin Guides		
Engine Truck Swing Bolsters		
Engine Truck Swing Links		
Equalizer Beams		
Eccentrics		
Eccentric Straps		
Fire Box Mud Rings		
Foot Plates		
Frames		
Frame Braces		
Fulcrum Shaft Bearings		
Fulcrum Castings		
Guide Yokes		
Guide Yoke Knees		
Grate Shaft Bearings		
Link Motion Supports		
Lift Shafts		
Pilot Frame Ends		
Pilot Frame Tops and Bottoms		
Pedestals		
Pistons		

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
LOCOMOTIVE CASTINGS, Con.		
Rocker Arms.....	J	Annealed
Rocker Boxes.....		
Reverse Shafts.....		
Runboard Brackets.....		
Rubbing or Chafing Irons.....		
Radial Bar Cross Tie Caps.....		
Side Bearings.....		
Spring Rigging Posts.....		
Spring Saddles.....		
Spring Scats.....		
Spring Hanger Plates.....		
Scoop Levers.....		
Steam Chests.....		
Transmission Bars.....		
Trailing Truck Brakes.....		
Levers.....		
Pan Bottom Segments.....		
Pan Scrapers.....		
D		
Deck Plate.....	Special	
Die Rings.....	K	6
Dies.....	K	6
Dises.....	All types	
Dredge Bucket Lips.....	Special	
Drop Forgings.....	All types	
Driving Axles.....	A, D	2 and 1
E		
Eccentric Rods.....	A	2
Eccentric Shafts.....	A	2
Electric Car Axles.....	A	2
Electric Car Construction.....	All types	
Eye Bars.....	A	2
F		
File Steel.....	H	6
Feedwater Heater Tubes.....	E, F	1, Normal
Field Gun Carriage Axles.....	A	2
Fire Box Plate.....	E	{ Normal or Annealed

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
F		
Flats	All types	
Freight Car Axles	A	2
Frogs and Switches	Special	
FORGINGS		
Automobile Forgings	All types	2
Drop Forgings	"	2
Locomotive Forgings	"	1 and 2
Stationary Engine Forgings	"	1 and 2
Marine Engine Forgings and Pins	"	1 and 2
G		
Gas Engine Construction	All types	
Gearing and Gear Wheel-Blanks	A, D, E	2, 3, 5, 6, 7
Girders	A, E	Normal
Grinding Mill Tires	G	6
Gudgeon Pins	E	7
Guns	A, D	2 and 5
Gears—Clash	E	7
Gun Barrels	A, D	2 and 5
Gun Forgings	A, D	As required
Gun Hoops	A or D	"
Gun Shield	Special	
H		
Hammer Piston and Hammer Piston Rods	A	2
Holding Down Bolts for Gun Mounts	A	1 and 2
Hollow Piston Rods	A	2
Hollow Shafting	A, E	2
Hydraulic Cylinders	Special	
I-K		
I-Beams	A, E	Normal
Keys	A, D	As required
Knuckles	Special	
L		
Locomotive Axles	A	2
Locomotive Boiler Plate	E	Normal, 1
Locomotive Castings	J	Annealed
Locomotive Piston Rods	A	2
Locomotive Stay Bolts	F	Normal
Locomotive Tires	G	As required

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
LOCOMOTIVE FORGINGS		
Axles.....	A	2
Connecting Rods.....	A	1 and 2
Crank Pins.....	A, D	2
Cross Heads.....	J	Annealed
Guides.....	J	Annealed
Pedestal Cap Bolts.....	A	1 and 2
Piston Rods.....	A	2
M		
Marine Boiler Plate.....	E	Normal
Marine Boiler Tubes.....	E, F	Annealed-
Marine Engine Piston Rods.....	A	Normal
Magnet Steel.....	Special	2
MARINE ENGINE FORGINGS AND SHAFTING		
Connecting Rods.....	A	1 and 2
Crank Pins.....	D, A	2
Crank Shafts.....	A	2
ORDNANCE		
Gun Forgings.....	A, D	2
Gun Shields.....	Special	
Projectiles.....	Special	
Rifle Barrels and Small Arms.....	A, D	2
P		
Passenger Car Axles.....	A	2
Pedestal Cap Bolts.....	A	1 and 2
Pinions.....	A, D, E, G	As required
Pneumatic Tools.....	Special	"
Projectiles.....	Special	
Propeller Shafts.....	A	2
Punches.....	K	6
PISTON RODS		
Locomotive Piston Rods.....	A	2
Marine Engine Piston Rods.....	A	2
Stationary Engine Piston Rods.....	A	2
Steam Hammer and Rock Drill Piston Rods.....	A	2

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
PLATE		
Artillery Plate.....	Special	
Boiler (Marine, Locomotive and Stationary) Plates.....	E	Normal- Annealed
Deck, Hull and Ship Plates.....	E	Normal
Fire Box Plates.....	E	Normal- Annealed
Protective Deck Plates.....	Special	
Armor Plate.....	Special	
R		
Rails.....	Special	
Rail Frogs and Switches.....	Special	
Rifle Barrels and Small Arms.....	A, D	2
Rivets.....	E	Normal
Rods.....	All types	
Rope.....	A, D	As required
Rounds.....	All types	
Rotary Rock Cutters.....	H	6
ROLLED MATERIAL		
Bars.....	All types	
Billets.....	“	
Blooms.....	“	
Flats.....	“	
Rounds.....	“	
Slabs.....	“	
Squares.....	“	
S		
Safe Deposit Vaults.....	Special	
Sheets.....	All types	
Shells.....	Special	
Ship Plate.....	E	Normal
Side Rods.....	A	1 and 2
Spindles.....	D or K	6
Springs and Spring Steel.....	D	4
Squares.....	All Types	
Stationary Boiler Plate.....	E	Normal
Stationary Engine Piston Rods.....	A	2
Stay Bolts.....	F	Normal
Steam Hammer and Rock Drill Piston Rods.....	A	2

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
S		
Stern Wheel Shafting	A, D	2
Structural Steel	All types	
Superheater Tubes	E, F	1, Normal
Shear Knife Steel	D, K, H	6
Saw Steel	H	6
Switches	D and Special	
T		
T-Bars	All types	
Tanks for Compressed Oxygen, Carbonic Acid, Hydrogen, etc.	A	2
Tender Truck Axles	A	2
Tie Rods	A	1
Tires (Locomotive and Grinding Mill)	G	As required
Tool Steels and Tools	H, K	6
	Special	6
Transmission Parts	A	2
TUBING		
Automobile Boiler Tubing	E	Annealed
Bicycle Tubing	E	1 and 2
Condenser Tubing	E, F	1, Normal
Feedwater Heater Tubing	E, F	1, Normal
Torpedo Tubes	Special	
Marine Boiler Tubing	E, F	Annealed- Normal
V		
Valve Stem Forgings	A	2
W		
Watch Springs	D, Special	4
Wheels	D, Special	As required
WIRE		
Cables	A, D	As required
Springs and Spring Steel	D	4
Z		
Z-Bars	All types	

NOTE.—In all cases where normal steel is recommended, the product of the mill should preferably be annealed at a dull red heat to remove rolling strains.

Results of some Comparative Tests made on All Grades of Steel

to determine relative strengths and properties of fatigue resistance

The results on each Steel are collectively combined into a "Quality Figure"

No.	STEEL	HEAT TREATMENT	APPROXIMATE CHEMICAL ANALYSIS					STATIC FIGURES				PROCESS OF MANUFACTURE	REMARKS
			C.	MN	CR.	NI.	V.	ELASTIC LIMIT lbs. sq. in.	TENSILE STRESS lbs. sq. in.	ELONGATION %	REDUCTION OF AREA %		

ELASTIC LIMITS—30,000—60,000 lbs. per square inch.

1	Mild Vanadium Steel	Annealed	.31					32,150	54,400	59.0	44.0	60.1	1111	2143	Open Hearth	Scrapped after service
2	Old Boiler Plate	Raw	.24	.42				58,100	70,840	82.1	25.5	53.4	612	1901	Open Hearth	
3	Mild Carbon Steel	Annealed	.18	.40				39,400	60,650	65.1	35.0	62.6	871	2152	Open Hearth	
4	" "	O.T. 900/425	.18	.40				45,300	70,030	64.6	33.0	64.0	777	2258	Open Hearth	
5	Carbon Forging Steel	Annealed	.26	.28				43,000	61,850	69.5	34.0	63.4	1415	3858	Open Hearth	Shafting steel
6	" "	O.T. 900/550	.26	.28				52,200	77,310	67.5	28.0	65.3	1175	4008	Open Hearth	Specially selected
7	Vanadium Casehardening Steel	Annealed	.15	.25	.30		.12	44,700	50,990	80.0	45.0	69.0	1958	6051	Open Hearth	Sliding gear steel
8	Chrome-Nickel Steel	Annealed	.36	.34	.95	1.70		56,500	81,370	69.5	32.0	68.5	978	3787	Crucible	
9	Carbon Steel Casting	Annealed	.65					34,600	58,800	57.0	28.0	44.9	269	419	Acid Open Hearth	
10	Vanadium Steel Casting	Annealed	.19	.60			.076	44,300	70,250	63.0	25.5	44.9	850	1671	Acid Open Hearth	Used for Car Wheels
11	Cr-Va. Steel Casting	Annealed	.57	.68	.75		.16	52,300	92,900	56.3	16.0	20.5	656	704	Basic Open Hearth	(NB—High Carbon Steel)

ELASTIC LIMITS—60,000—100,000 lbs. per square inch.

12	Nickel Forging Steel	Annealed	.21	.45		3.70		61,100	79,700	76.7	30.0	62.5	746	2851	Basic Open Hearth	
13	" "	O.T. 900/550	.21	.45		3.70		77,100	98,470	78.3	25.0	65.3	664	3345	Basic Open Hearth	
14	Chrome-Vanadium Forging Steel	Annealed	.26	.50	1.00		.16	61,900	92,900	66.6	25.0	57.3	1608	5706	Basic Open Hearth	Known as Type "A"
15	Carbon Spring Steel	Annealed	1.00	.30				63,800	125,000	51.0	8.5	15.2	1260	1222	Open Hearth	
16	Chrome-Vanadium Spring Steel	Annealed	.40	.77	1.22		.19	67,500	100,600	67.1	26.0	61.7	1406	5858	Crucible	Known as Type "D"
17	Chrome-Nickel-Vanadium Steel	Annealed	.30	.27	1.51	3.45	.085	69,100	96,880	71.3	28.5	68.5	507	2402	Crucible	Imported Automobile Steel
18	Nickel-Vanadium Steel	Annealed	.24	.72		3.40	.15	79,200	99,700	79.5	25.0	64.0	798	4048	Basic Open Hearth	
19	Chrome-Nickel-Vanadium Steel	Annealed	.57	.27	.93	2.04	.07	95,100	129,100	73.7	21.0	49.8	983	4659	Crucible	
20	Chrome-Nickel Steel	Tempered	.37	.84	.89	1.70		86,000	102,700	83.8	22.0	63.8	702	3855	Crucible	

ELASTIC LIMITS—100,000 lbs. per square inch and over.

21	Carbon Spring Steel	O.T. 900 450	1.00	.30				101,000	186,300	54.2	9.5	16.1	561	912	Open Hearth	Spring Temper
22	Chrome-Vanadium Spring Steel	O.T. 900 450	.40	.77	1.22		.19	195,300	208,500	93.7	10.0	36.3	480	3403	Acid Open Hearth	Spring Temper Type "D"
23	Chrome-Vanadium Forging Steel	O.T. 900 550	.30	.50	1.00		.16	141,500	151,750	93.0	16.0	56.2	717	5705	Basic Open Hearth	Type "A" Crankshaft Temp.
24	Nickel-Vanadium Steel	O.T. 900 550	.24	.72		3.4	.15	129,900	134,600	96.4	18.0	64.8	626	5270	Basic Open Hearth	
25	Chrome-Nickel-Vanadium Steel	O.T. 905 550	.30	.27	1.51	3.45	.085	152,300	159,900	95.2	17.0	58.9	487	4869	Crucible	Imported Automobile Steel
26	Chrome-Vanadium Spring Steel	O.T. 900/550	.40	.77	1.22		.19	183,400	187,600	97.7	14.0	50.6	634	5883	Crucible	
27	Chrome-Nickel Steel	Tempered	.36	.84	.95	1.70		134,500	150,800	89.5	15.5	53.5	579	4166	Crucible	

NOTES

STATIC TESTS MADE ON SAMPLES 1/2" DIA. X 2" LONG.

DYNAMIC TESTS MADE ON LANDGRAF-TURNER ALTERNATING

IMPACT MACHINE. (OLD FORM)

QUALITY FIGURE IS PRODUCT OF:
ELASTIC LIMIT
REDUCTION OF AREA
DYNAMIC FIGURE
DIVIDED BY ONE MILLION, OR
E x R x A
10⁶
= QUALITY FIGURE

Type “A” Vanadium Steels

This is perhaps the most adaptable of all types of Vanadium Steel. It has great static strength and ductility, with stupendous resistance to shock and fatigue.

Under trip-hammer dies or drawing dies, it works comparably with soft open-hearth steel.

In drop forging, it flows readily in the die, withstands high temperatures without deterioration and takes a high finish.

It is easily machined.

It is essentially an oil tempering forging steel, though it is much used for casehardened gears and other parts where great strength of core is required. These parts are usually heat-treated to give an elastic limit of 100,000 to 110,000 pounds, with a tensile strength of 120,000 to 130,000 pounds per square inch; an elongation in 2 inches of 18% to 20% and a reduction of area of about 60%. Much higher elastic limits are regularly obtained for crank shafts, propeller shafts, etc., when desired.

Casehardened gears from mild Type “A” Chrome-Vanadium steel, carbon under .25%, are being extensively used on automobiles. The case is hard, tough, strong and wear-resistant to a very high degree. The hardness is about 90, scleroscope test. It is strongly coherent to the core and gives no trouble from flaking, powdering or flowing under pressure. The core is very strong and tough, the physical properties being about:

Elastic Limit	Ultimate Strength	Elongation % in 2 Inches	Reduction of Area
180,000	200,000	8%	25%

The heat treatment of casehardened gears is usually a double one. After carbonizing, they are reheated to 900° C. and quenched in oil, then reheated to 800° or 825° C., quenched in water and finally heated to about 200° C. in oil for half an hour to release strains.

Type "A" Vanadium Steels

Drop Forged Type "A" Vanadium Steel Crank Shaft

Distorted by repeated blows under 2500 lb. Steam Hammer with no sign of a fracture at any point.

Due to the shock and impact this is much more severe test than if done under gradual pressure of hydraulic presses.



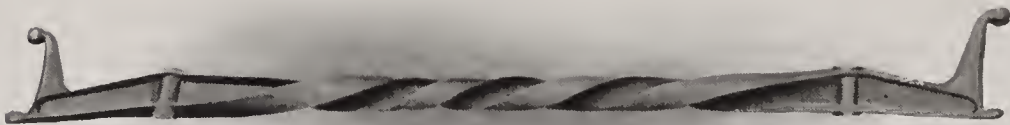
Analysis of this Steel

Sulphur	0.057%
Phosphorus . .	0.010
Manganese . .	0.43
Carbon	0.33
Chromium . .	0.96
Vanadium . .	0.18

An excellent .35% Carbon Steel shaft was subjected to like test but could not be distorted to the same extent without fracture, the force exerted to an equal number of blows being only one-fourth that required to distort the Type "A" Vanadium Steel shaft.

Statically, an untreated bar of Type "A" steel gave the following figures :

Elastic Limit,	lbs. per sq. inch	.	106,233	Elongation in 2 inches, per cent.	23.8
Tensile Strength	" " " "	.	123,070	Reduction of area	" " 49.4



Drop Forged Automobile Axle—Twisted Cold

Type "A" Vanadium Steels



Knot Tied Cold 1-inch Diameter Bar

100,000 lbs. per square inch elastic limit



Drop Forged Automobile Steering Knuckle

Maximum diameter of barrel $1\frac{3}{8}$ in., minimum diameter $\frac{7}{8}$ in. Diameter of collar $1\frac{1}{8}$ in.

Maximum diameter of shank 1 in., minimum $\frac{5}{8}$ in. Diameter of shank boss $\frac{7}{8}$ in. Arm length $6\frac{1}{2}$ in.



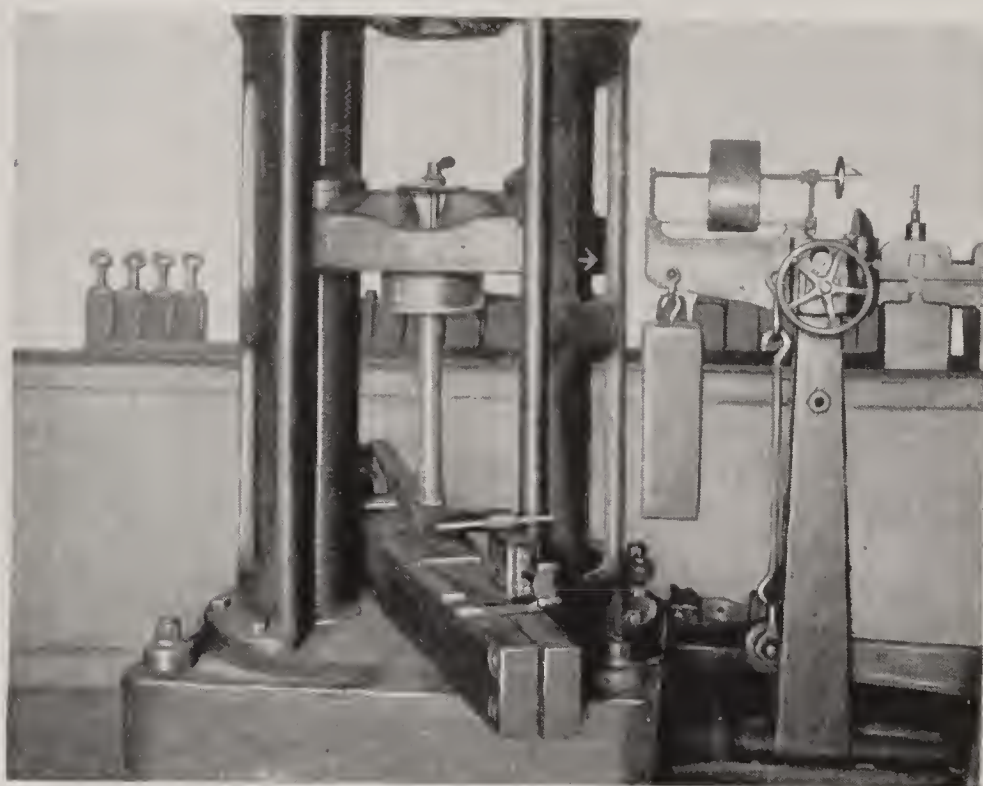
Spring Coil

Steel 9-16 in. x 7-16 in. was hardened in oil and then subjected to crushing test in hydraulic press. It required 210,000 lbs. to distort and over 400,000 lbs. final pressure to bend to present condition. This test was repeated on opposite end of coil without sign of fracture

Type “D”

This type is essentially suited for manufacture of springs, and is also used for gears in constant mesh, rifle barrels, high tensile wire and similar work.

In springs it has double the co-efficient of safe working load of carbon spring steel; it is easily “welded” and in service can be repeatedly overloaded without serious deterioration; it has an elastic limit of from 180,000 to 225,000 pounds per square inch, with tensile strength ranging from 190,000 to 250,000 pounds. Spring makers guarantee it to have three times the life of carbon steel springs.



Test of short seven-leaf Automobile Spring, showing elastic limit at fibre stress of 214,000 lbs. per square inch

A comparative test of Type “D” vs. chrome-nickel spring steel:

Both test pieces 25 inches long, of same width and gauge, with a 4-inch arc. In six plunges flat against the face of testing machine—

Type “D” steel took permanent set of $\frac{3}{16}$ inch.

Chrome-nickel steel took permanent set of $\frac{3}{4}$ inch.

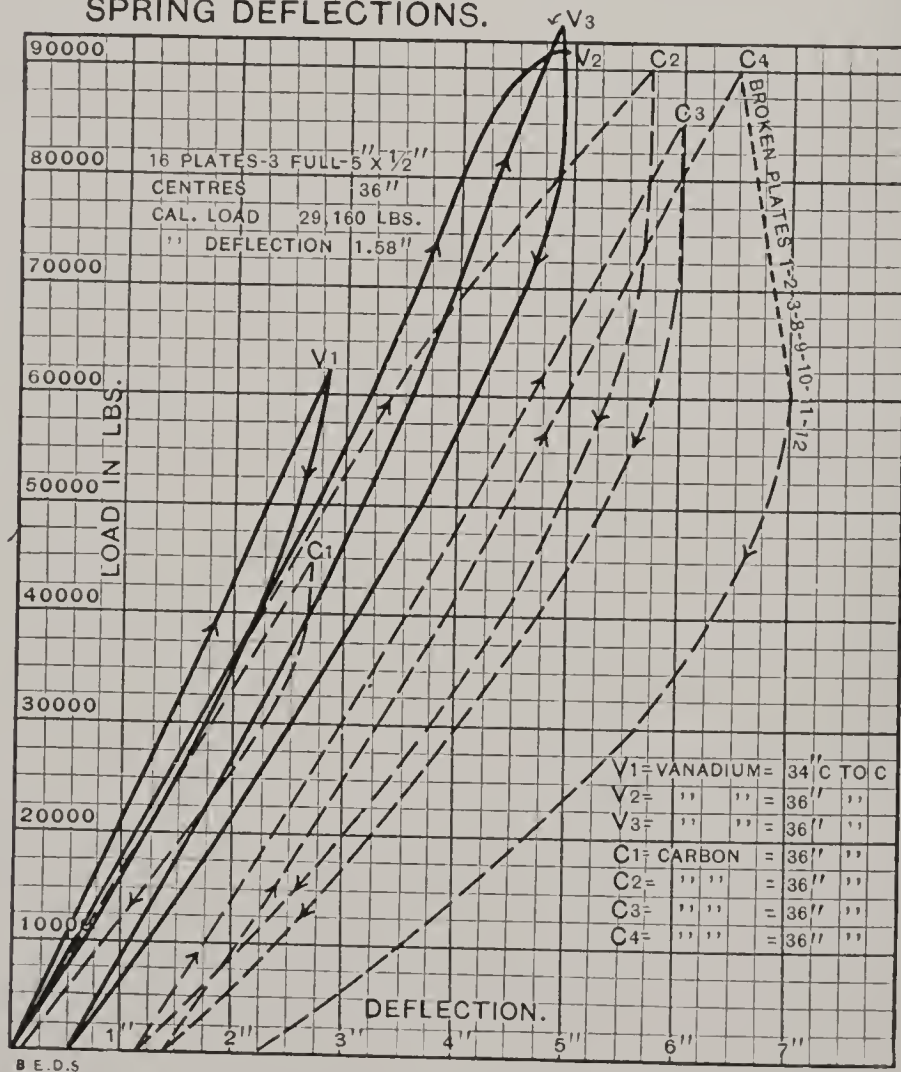


Type "D" Vanadium Steel Locomotive Driving Spring

Under load corresponding to stress of 110,000 lbs. per square inch, this spring withstood 23,620 compressions

Under load corresponding to stress of somewhat less than 90,000 lbs. per square inch, a Carbon Steel Spring has either broken or the steel became "dead" and lost its camber before reaching 10,000 deflections

SPRING DEFLECTIONS.



Comparative tests of Vanadium and Carbon Steel Locomotive Springs
(Tested by American Locomotive Company)

(See next page)

Spring Tests, Type "D"

(See Curves on page 38.)

The Vanadium Spring was Tested:

1. To 62,700 pounds with 34-inch centres.
2. To 92,000 " " 36 " "
3. To 94,000 " " 36 " "

On second test, Elastic Limit was reached at 85,000 pounds, or 234,500 pounds Fibre Stress with Permanent Set of .48 inches.

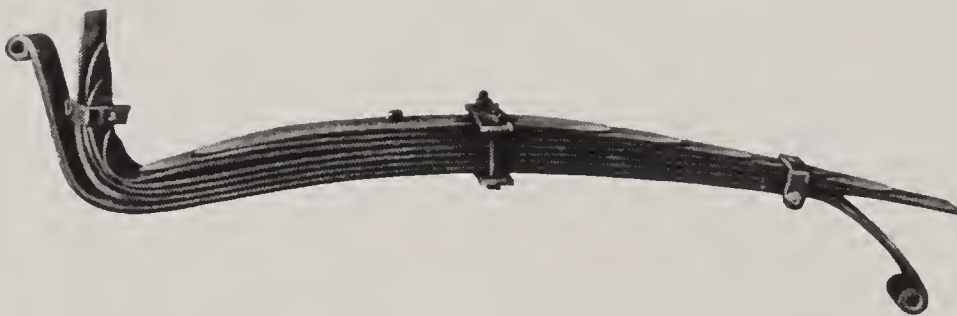
The Third Test was repeated three times without the least variation from recorded heights.

The Carbon Spring was Tested:

1. To 44,000 pounds with 36-inch centres.
2. To 89,280 " " 36 " "
3. To 84,520 " " 36 " "
4. To 89,280 " " 36 " "

On Second Test, Elastic Limit was reached at 65,000 pounds, or 180,000 pounds Fibre Stress with Permanent Set of 1.12 inches.

On Third Test it took an additional set of .26 inches and on Fourth Test, plates 1, 2, 3, 8, 9, 10, 11 and 12 failed at the centre.



Vanadium Steel Spring

Taken from an automobile that was completely wrecked
by running into a stone wall

These tests indicate that Vanadium Steel is far superior to carbon steel and is particularly to be recommended where the severest service conditions are encountered.

Type "D"

Type "D" gears possess great strength and toughness, a high degree of hardness and great resistance to wear. Their physical properties average about as follows:

Elastic limit ----- 200,000 to 220,000 pounds per square inch.
 Ultimate strength --- 215,000 to 250,000 pounds per square inch.
 Elongation in 2 inches, 12.0 % to 10.0 %.
 Reduction of area ---- 45.0 % to 35.0 %.

The heat treatment generally used is to quench in oil from a temperature of 900° C. and draw back, preferably in lead, at 450° C.

Chrome-Vanadium steels retain their elastic limit and hardness to a remarkable degree at elevated temperatures, and on this account Type "D" steel has proved a very efficient material for gas engine exhaust valves.

Type "E"

This type of steel is especially designed for casehardening. The essential features of good casehardening steel, the results obtainable from Type "E" casehardened Vanadium Steel and the logical reasons involved, have already been fully dealt with on page 18 et seq:



Type "E" Vanadium Casehardened Steel

(3 times natural size)

½-in. bar casehardened by the process detailed on page 19

Note the tough break of the soft core, in conjunction with the depth of casing for such a small article

Briefly epitomized, the advantages of Type "E" steel comprise (1) strong case, (2) powerful resistance to abrasion of such case, (3) close cohesion of such case to the softer core, (4) absence of "flaking away" or powdering away of such case, (5) a core which is exceedingly ductile and at the same time has great strength and resistance to disintegration.



Type "E" Casehardened Vanadium Steel
(3 times natural size)

This steel was casehardened in the perfect round section, and after quenching, was beaten out COLD to the shape shown, under a heavy power hammer.

Note strong adhesion of the case to the core and the ductile nature of the core

Type "G"

This type is designed for locomotive tires. It has high static strength, and withstands 1260 alternations before fracture under the alternating impact test, or more than double the number withstood by the regular grade of tire steel.

It is very homogeneous and machines quite readily; it combines superlative resistance to wear with an excellent adhesive surface—qualities of the utmost importance in a tire.

Type “H”

This type of steel is intended especially for cutting tools, such as rotary cutters, etc. With some slight modifications as to carbon and manganese content, it is admirably adapted for use in manufacture of saw blades. It tempers accurately and evenly, and although hard, is extremely tough. For saws, this type presents these special advantages: Saws



Type “H” Vanadium Steel Saw with blade coiled

After remaining thus for a year, the blade was released,
and returned to perfect alignment

will not cramp in the cut; will not develop kinks; can be easily set without danger of fracturing the teeth; will retain the cutting edge more than twice as long as saws made from the regular carbon steel; and will hold the set and cut faster than any other saws.

Steel Castings



Type "J" Vanadium Steel Locomotive Transmission Bar,
Bent Cold

Type "J"

This type of steel is designed expressly for castings, which are thereby rendered solid and more nearly perfect. It pours quietly and freely and is readily welded; it has approximately 25 per cent increased elastic limit and 15 per cent greater tensile strength than the regular carbon steel casting; the ductility is maintained and there is no impairment of the machining qualities.

Type "J" steel is extremely tough and close in structure. It withstands under the Turner formula about the same num-

ber of alternations as ordinary forged steel of the same carbon content, *and twice that of the regular steel casting.*

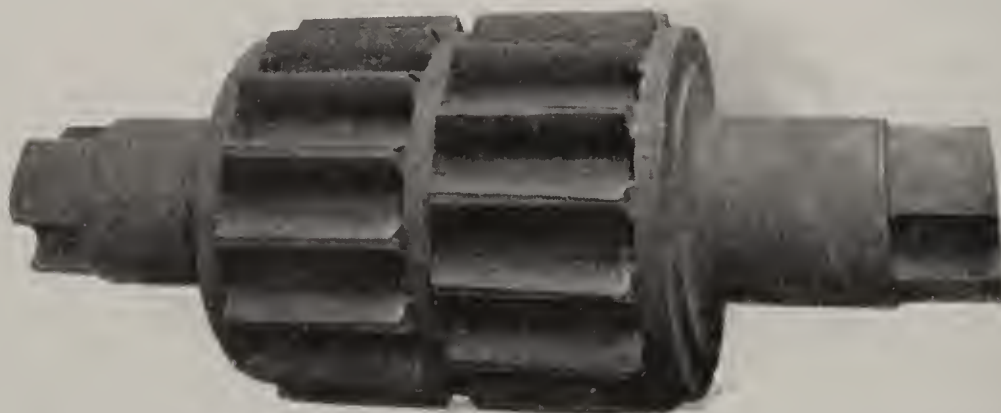
This latter point is of supreme importance. Almost invariably the service failure of a casting is not traceable to any lack of original static strength and ductility but rather to the fact that it has deteriorated rapidly under the vibration and repeated stresses incidental to its practical usage. It is not claiming too much to say that Vanadium Steel castings approximate in "life" qualities those of forged carbon steel.



Type "J" Vanadium Steel Engine Frame Section

Subjected to 20 blows from a 5000-lb. tup dropping from a height of 18 ft. in the clear; supports four feet apart

Regular steel frame section invariably breaks on either the first or second blow



Type "J" (Special)—45 in. dia. Vanadium Steel Mill Pinion

A $3\frac{1}{2}\%$ Nickel Steel Pinion, made by the same firm to same pattern, and placed in companion service in the same rolling mill, was worn out completely, while the Vanadium Steel pinion continued in service and presented this appearance after rolling 100% more tonnage than the nickel steel pinion

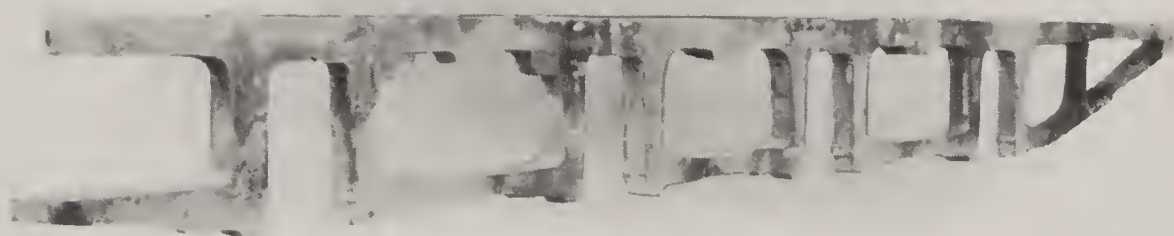
Type "J"



Type "J" Vanadium Cast Steel Engine Bed Plate for Marine Work

Weight, 1725 lbs. Tensile strength, 77,760 lbs. Elastic limit, 45,930 lbs.

Elongation in 2 inches, 30%; Reduction of area, 53.5%.

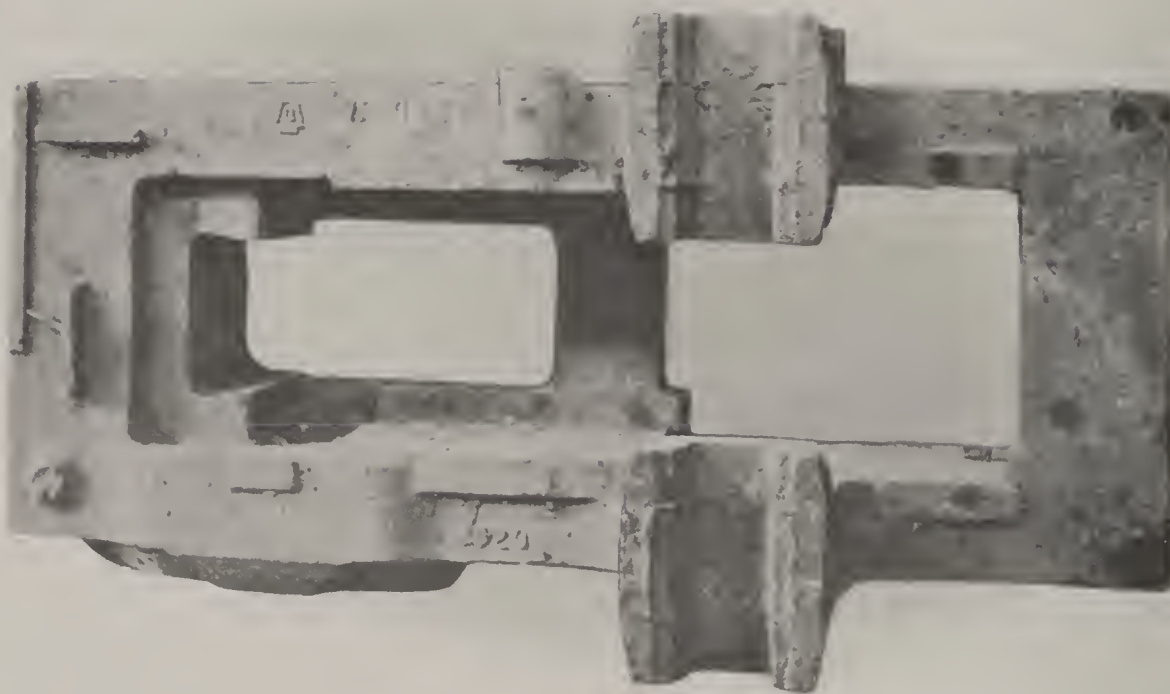


**Type "J" Vanadium Cast Steel Main Frame
for consolidation locomotives**

Weight, 5590 lbs. Tensile strength, 81,580 lbs. Elastic limit, 47,130 lbs.

Elongation in 2 inches, 30.5%; Reduction of area, 47.9%.

Type "J"



**Type "J" Vanadium Cast Steel Bed Plate for Upsetting Machine,
weight 12,900 pounds**

Tensile strength, 79,840 lbs. Elastic limit, 45,990 lbs.
Elongation in 2 inches, 27.5%; Reduction of area, 51.4%.



Type "J" Vanadium Cast Steel Locomotive Cylinder

Weight, 7355 lbs. Tensile strength, 80,620 lbs. Elastic limit, 48,920 lbs.
Elongation in 2 inches, 24.5%; Reduction of area, 44.2%.

Type "J"



Type "J" Vanadium Cast Steel Locomotive Driving Wheel Center,
72 Inches Diameter

Weight, 3450 lbs. Tensile strength, 75,740 lbs. Elastic limit, 47,080 lbs.
Elongation in 2 inches, 30%; Reduction of area, 51.6%.

All Vanadium Steel Castings are grouped generically under Type "J," but it must be distinctly understood that Type "J" does not invariably exhibit exactly the same chemical composition. For example, the rolling mill pinion shown on page 44 runs between .40 and .50 in carbon content, while standard Type "J" is given at .25 carbon. Other variations are made depending on the class of service required.

This is true of all types of Vanadium Steels described herein; before adopting any type as the fixed standard, a proper consideration of its intended application should determine both the composition and the subsequent heat treatment.

Type "K"

This type of steel is intended for the making of punches, dies, etc. It will not upset, is hard and tough and offers the ultimate resistance to crystallization attainable in steel of this "temper."



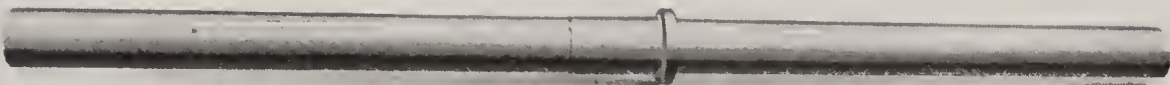
Type "K" Vanadium Steel Punches and Dies

5-16
4422 Holes

13-16
4402 Holes

13-16 Spl Die
5453 Holes

Special Types



Vanadium Steel Gas Engine Piston Rod
Rough Forging and Finished Piece

Eleven nickel steel piston rods in blowing engines of the gas type were broken in one year at a large blast furnace plant. Owing to its antifatigue and non-crystallizing properties, as well as to its increased strength and elastic limit, Vanadium steel forgings have been substituted. The following physical tests were obtained:

	Longitudinal Test	Transverse Test	Radial Test
Tensile strength.....	113,700 lbs.	108,820 lbs.	112,560 lbs.
Elastic limit.....	92,500 lbs.	90,860 lbs.	93,940 lbs.
Elongation in 2 inches..	20%	17%	15%
Reduction of area.....	58.1%	41.8%	41.3%

Heat treatment consisted in quenching in water from 907 deg. C. and drawing back at 710 deg. C.

Special Types



Vanadium Crucible Steel Cylinder Casting for Torpedo

Tensile strength, 80,000 lbs. Elastic limit, 65,000 lbs.
Elongation in 2 inches, 22%; Reduction of area, 43%
Flattened under a steam hammer



Type "H" Vanadium Steel Hot Forging Dies

Average life of Carbon Steel Dies, 2 days
These Vanadium Steel dies ran four months in the same machine on the same work
showing 60 times the life of carbon steel

Special Types



Pneumatic Hammer Riveting Die

Used in shipbuilding work, in continuous service fourteen months. Requirements drastic, as many of the $\frac{1}{8}$ -in. rivets are redriven cold against large flat bottom riveter. A large American shipbuilding concern reports the normal life of the tool steel dies they formerly used was ten hours, the main trouble being that the constant vibration crystallized the shank of the dies and they broke at point indicated by arrow



Reddington Flue Cutter Tool

Removed after cutting 5200 flues. Highest comparative record by other steel tested by same railway, 1000 flues

One large railway shop cut its consumption of this tool down from 1049 carbon steel tools to 68 Vanadium steel cutters in one year, and increased the total number of flues cut by 7134 pieces

Machining, Forging and Welding Qualities

The Vanadium steels are readily forged and give no trouble in the fire. It is of course to be noted that the same precautions are to be observed in their initial heating as are accorded to any high-grade steel. With regard to drop-forging, all the Vanadium steels flow readily in the dies and no trouble is experienced in the process, a fact which in this respect brings them into sharp contrast with some other alloy steels for which great merit is claimed as to mechanical attributes.

The ease with which the Vanadium steels can be machined is a matter of deep interest to the practical engineer. Broadly speaking, it will be sufficient to say that they are machined as easily as carbon steels of the same "temper."

Vanadium itself helps the welding qualities of iron, and this fact, coupled with its intensifying strengthening action (already alluded to), on such ingredients as are themselves inimical to successful welding (thereby greatly decreasing the amounts of such ingredients necessary to be used), makes the Vanadium steels the most weldable of all the alloy steels.

Uniformity of Vanadium Steel

Vanadium steels, *properly made by means of the right description of alloy* (this point is dealt with fully on page 53) are absolutely uniform. In considering this question of uniformity it should not be overlooked that: (1) As Vanadium will perform its scavenging function first, the amount of Vanadium that will *remain* in the steel will necessarily depend upon the degree to which the metal has been deoxidized before the Vanadium has been added; (2) As detailed hereinbefore at some length, an enormous readjustment of static and dynamic equilibrium takes place at the calescence point and therefore the *static* properties of two identical Vanadium steels, one of which has been finished or annealed above the calescence point and the other finished or annealed below the calescence point, must necessarily differ considerably. From this it is obvious that a conclusion of non-uniformity must not be hastily reached as the result of a simple test in one direction.

To these must be added the personal equation and those differences of shop practice which must exist in all steel making, so that degrees of limitation must necessarily be introduced.

Recapitulating

It may be said that the marvelous results in steel hereinbefore instanced which follow from the proper application of **“Amervan”** Ferro-Vanadium are caused by its expelling the injurious oxygen and nitrogen contents, by its toughening the carbonless portion of the iron, rendering it more impervious to the passage of carbides through it (thus ensuring a generally sorbitic distribution of those carbides in annealed steel, and a perfect distribution of emulsified carbides in tempered steel) and by its greatly intensifying the static strengthening action of those carbides.

Ferro-Vanadium Alloy

“Amervan” Ferro-Vanadium made by the American Vanadium Company is produced chemically, has a low fusing point, contains practically no carbon and ranges in Vanadium content from 30 to 40%—quality, quantities and deliveries being guaranteed absolutely.

As Vanadium produces its various effects through its action on totally different components of the steel, it will readily be seen that:

1. Two Vanadium alloys may easily be of the same ultimate composition analytically and yet give widely differing properties to steel on account of their elements being differently combined. The laboratory determination of this would be tedious and commercially impossible, though the microscope helps much, but manufacturing precautions can assure the reaching of the desired end.

2. The greater the degree of fusibility and solubility possessed by the Ferro-Vanadium, the more satisfactorily it should behave, other things being equal. Certain definite alloys, containing iron, silicon and Vanadium are much more fusible and soluble in molten steel than plain alloys of iron and Vanadium, and their use is advantageous in many cases.

3. Owing to the powerful affinity of Vanadium for oxygen and to the fact that the major portion of it is required for other purposes, Vanadium alloys should only be added under deoxidizing conditions to metal that has previously been as well deoxidized as possible in the ordinary circumstances under the control of the steel maker.

4. Lastly, it must be remembered that, chemically speaking, Vanadium is the radicle of a powerful acid, and therefore it must be kept from contact at a high heat with any material of a basic nature, such as calcareous slag.

Before closing, it may be of interest to touch briefly on the various simple courses of procedure which should be followed for the successful manufacture of Vanadium steel by the different commercial processes in common use.

The Crucible Process

In the crucible process the charge is made up of such ordinary stock as the specifications may call for; any chrome or nickel may be included in the initial charge; some makers add the Vanadium to the charge; others wait until the charge is thoroughly dead melted or "killed," when they add the Vanadium alloy, avoiding contact with the slag as far as possible, together with such extra manganese, in the form of ferro-manganese, as the special circumstances of the case may dictate. After the expiration of 20 to 30 minutes the contents of the crucible are to be skimmed and poured as usual.

Acid Open-Hearth Process

In acid open-hearth practice, the furnace charge should be melted as usual, worked down with ore to a carbon percentage at least thirty points above the percentage of carbon to which it is desired to work down the bath, and preferably "shaken down" for the remainder of the way. At the finish, the slag should be "supersilicated," that is, it should contain at least 52% of silica, and should not contain excess of oxide of iron; in other words, in melter's parlance it should be "neutral." The fracture of the slag, and its "thickness" in proportion to the heat present, will tell the story to the practical eye. Any necessary proportion of ferro-chrome,

warmed on the breast of the furnace is next added, and a few minutes later the ferro-manganese and "warmed" silicon pig. After their incorporation the flame is "blanketed" and the Vanadium alloy added in large pieces; three minutes will suffice for its working through the bath, which is meanwhile rabbled. Tapping and teeming are then performed as usual. Any nickel may be charged at the outset.

Basic Open-Hearth Process

In basic open-hearth practice the furnace is charged with good stock and limestone, any required nickel being also added. The charge is melted and worked down to about the same point as in acid practice, then "shaken down" to the necessary degree of decarburization. The slag must be in good condition and free from excess of cutting oxides. The necessary ferro-chrome is now charged, due allowance being made for loss; in good practice a charge of 1.3% of chromium (in ferro-chromium) should give 1% of chromium in the residual steel. It may be necessary to closely follow this addition with a little fluorspar in order to keep the slag sufficiently open. Ferro-manganese is then added in lump form to the bath, and when the metal additions are incorporated, the furnace is tapped. After a small quantity of steel has run into the ladle, the Ferro-Vanadium and any further high grade ferro-silicon required, both broken up small and preferably preheated, are added, all additions being completed before slag appears. Rabbling the contents of the ladle greatly assists matters.

Bessemer and Tropenas Practice

In Tropenas practice the converter is charged and blown as usual, and "deoxidation" performed in the converter with manganese and silicon. The Ferro-Vanadium is added in the ladle as in basic practice, the metal being "skimmed" as it issues from the converter. Nickel would be added with the charge and chrome before or with the deoxidants.

The same remarks would apply to Bessemer practice as to Tropenas practice. The preparation of high grade alloy steels is not usually attempted in the Bessemer converter.

“Loss” in Addition

The percentage of “loss” concomitant with the addition of Vanadium has often been asked. For obvious reasons it is impossible to give a simple answer on this point, as that portion of Vanadium used up in doing scavenging work passes into slag. This point has been dealt with on page 15.

Vanadium in Cast Iron

Cast Iron may be regarded as a more or less impure steel, containing, in addition to the usual elements present in steel, a comparatively large quantity of carbon in the form of graphites, interspersed throughout its structure in the form of granules, flecks or plates. The graphite destroys the continuity of the metal, and in consequence, the limit of strength of cast iron is low as compared with steel.

It also follows that any improvement conferred upon cast iron by an alloy must necessarily not be as great as in the case of the more homogeneous steel. In the case of cast iron also, we have a metal that is subjected to no work or heat treatment to develop its latent qualities. Nevertheless the benefits which accrue from the addition of small percentages of Vanadium to cast iron, especially in chill and cylinder castings, are very great, even if they are not so spectacular in their nature as those obtained in steel.

Vanadium not only cleanses the iron from oxides and nitrides, but also exercises a very strong fining effect on the grain of the iron, with the result that porousness is eliminated and sound castings are produced. Strength, rigidity and resistance to wear are all increased by the addition of Vanadium to gray cast iron. In the case of chilled cast iron, Vanadium produces a deeper, stronger chill and one less liable to spall or flake.

Tests: As a result of two years test on a pair of cylinders made of Vanadium cast iron, one of the large railroads specified Vanadium cast iron for the cylinders of 183 new locomotives built during the past year or two. The pair of cylinders under test gave upward of 200,000 miles with only micro-

meter wear, whereas ordinary locomotive cylinders will show about $\frac{1}{32}$ -inch wear per 100,000 miles. Comparative tests have been made by the builders of these locomotives between iron containing Vanadium and the iron to which no Vanadium was added. The average of ten consecutive days' tests was as follows:

	Transverse	Tensile
Plain Cast Iron	2130	24225 lbs.
Vanadium Cast Iron	2318	28728 "

The transverse tests were made on bars 1 inch square, 12 inches between supports; the bars were machined all over and consequently were absolutely comparable, which is not the case with bars tested as they are cast. The tensile tests were also machined. In machining the Vanadium cast iron cylinders, the effect of Vanadium was noticed in the machining qualities of the iron; the chips were longer, tougher and showed considerable springiness. Another concern making cylinders for gas engines has recently reported results as follows:

	Transverse	Tensile
A Plain Iron	2860	21000 lbs.
AV Vanadium Iron	3300	24000 "
B Plain Iron	3487	25000 "
BV Vanadium Iron	3770	27650 "

These transverse tests were made on bars 1 inch square, 12 inches between supports, and we understand were not machined. The "AV" and "BV" cast iron, containing Vanadium, have stood 750 pounds water pressure with $\frac{3}{4}$ -inch thickness of metal.

Application: In applying Vanadium to cast iron, it must be remembered that nothing like the heat of molten steel is at hand, consequently one should use a finely crushed or powdered alloy of low melting point. As the melting point depends directly upon the percentage of Vanadium contained in the alloy, a Ferro-Vanadium containing under 35% Vanadium should be used.

Cupola Iron: Where the iron is melted in the cupola, it is necessary to add the Ferro-Vanadium to the ladle; and as the

amount of heat available for dissolving the Ferro-Vanadium is limited, the iron should be tapped out as hot as possible and a ladle used that has just been emptied in order to conserve as much heat as possible. After the bottom of the ladle is covered with a few inches of iron, the finely crushed or powdered Ferro-Vanadium is added by sprinkling it on the stream as it flows down the spout to the ladle; in this way advantage is taken of all the available heat and also of the mixing effect of the stream as it strikes the iron in the ladle. After the Vanadium is added the contents of the ladle should be well stirred and allowed to stand a few moments in order to ensure thorough incorporation and complete reaction. Owing to the limited heat available in cupola iron, it has been found that the addition of .10 to .12% Vanadium (equivalent to $4\frac{1}{2}$ to 5 ounces of 35% Ferro-Vanadium per 100 pounds of metal) is all that should be attempted ordinarily.

Air Furnace Iron: In the case of the higher grade air furnace iron, with its reserve of available furnace heat, this procedure is very simple: after the charge is melted and 15 to 20 minutes before tapping, the Ferro-Vanadium is added and the bath well stirred or rabbled. The addition of .18 to .20% Vanadium is recommended in this case, equivalent to 10 to 11 ounces of 35% ferro-vanadium per 100 pounds of metal.

Malleable Iron: Tests of Vanadium in malleable cast iron have been reported satisfactory in every way, the fibre of the iron showing much cleaner and the tensile strength improved about 12%; the castings were also much stiffer than ordinary malleable castings.

Vanadium in Wrought Iron

The incorporation of Vanadium in wrought or puddled iron is theoretically much more difficult, because wrought iron is essentially a precipitated metal, permeated more or less by frozen mother liquor of iron (in which latter the Vanadium is more especially contained), and also because the slag of the puddling furnace is strongly basic in its nature and removes Vanadium from the bath much as it removes phosphorus.

We have never met with a Swedish puddled iron containing much over 0.02% of Vanadium, while the acid open-hearth steel made from pig iron smelted from the same ore frequently contains 0.08% of Vanadium and upwards.

It will thus be seen that only in wrought iron does the correct addition of Vanadium present any difficulty, and results follow with certainty as long as due cognizance be taken of the simple facts concerning its properties and attributes, as detailed in the foregoing.

Conclusion

In fact, Vanadium has placed in the hands of the thinking metallurgist a resource whose power can hardly at present be estimated.

Broken railway axles and engine frames should soon be placed in the history of the past; an amount of energy can be transmitted by or stored up in a shaft of incredible lightness; springs may be made nearly half the weight of the best now existing and yet possess better tenacity and longer life; ships can be driven at increased speeds with safety; the flying-machine problem comes a step nearer solution; while the questions of the submarine, torpedoes, armorplate, big guns and their carriages, projectiles and the like, enter on a new phase, and in bridge building spans become possible that were not contemplated in the most sanguine moments of the designer of a few years ago. These are all rendered possible by the judicious harnessing of an element which, with its compounds, was looked upon up to a few years ago almost as a chemical curiosity.

The application of Vanadium to steel manufacture constitutes perhaps its most important employment. Very promising results have been obtained by means of its adaptation to copper and to some of the other metallic alloys, but here a totally different set of conditions is encountered and much work is now being done in this direction. In cast iron too, changes little short of revolutionary are daily being wrought by the truly wonderful element Vanadium.

“Amervan” Ferro-Vanadium

“The Master Alloy”

is used in the manufacture of Vanadium Iron
and Steel by these companies and many others

VANADIUM CAST IRON

Capitol Foundry Company	Hartford, Conn.
Du Bois Foundry Company	Cold Spring, N. Y.
Manufacturers Foundry Company	Waterbury, Conn.
National Malleable Casting Company	Chicago, Ill.
Rosedale Foundry & Machine Company	Pittsburgh, Pa.
Ross-Meehan Foundry Company	Chattanooga, Tenn.
W. P. Taylor Company	Buffalo, N. Y.
Waterbury Castings Company	Waterbury, Conn.
Wellsburg Foundry & Machine Company	Wellsburg, W. Va.

VANADIUM CAST STEEL—(Crucible)

Crucible Steel Casting Company	Lansdowne, Pa.
Crucible Steel Casting Company	Cleveland, Ohio
Damaseus Crucible Steel Casting Company	New Brighton, Pa.
Lebanon Steel Casting Company	Lebanon, Pa.
Michigan Crucible Steel Casting Company	Detroit, Mich.
Riverside Steel Casting Company	Newark, N. J.
Sivyer Steel Casting Company	Milwaukee, Wis.
West Steel Casting Company	Cleveland, Ohio

(Open Hearth)

American Steel Foundries Company	Chicago, Ill.
Mackintosh-Hemphill Company	Pittsburgh, Pa.
Malleable Iron Fittings Company	Branford, Conn.
Mesta Machine Company	Pittsburgh, Pa.
Montreal Steel Company	Montreal, Canada
Penn Steel Casting & Machine Company	Chester, Pa.
Pittsburgh Steel Foundries	Pittsburgh, Pa.
Pratt & Letehworth	Buffalo, N. Y.
Union Steel Casting Company	Pittsburgh, Pa.
United Engineering & Machine Company	Pittsburgh, Pa.
Wheeling Mould & Foundry Company	Wheeling, W. Va.

VANADIUM MALLEABLE IRON—(See Cast Iron)

VANADIUM TOOL STEEL

Bethlehem Steel Company	South Bethlehem, Pa.
Colonial Steel Company	Pittsburgh, Pa.
Crucible Steel Company of America	Pittsburgh, Pa.
Cyclops Steel Company	Titusville, Pa.
Halcomb Steel Company	Syracuse, N. Y.
Heller Bros. Company	Newark, N. J.
Midvale Steel Company	Philadelphia, Pa.
Vanadium Alloys Steel Company	Latrobe, Pa.
Vulean Crucible Steel Company	Aliquippa, Pa.

VANADIUM FORGINGS—(Crank Shafts, Axles, Piston Rods, etc.)

American Locomotive Company	New York, N. Y.
Carnegie Steel Company	Pittsburgh, Pa.
L. L. Driggs & Company	New York, N. Y.
Erie Forge Company	Erie, Pa.
Mesta Machine Company	Pittsburgh, Pa.

DROP FORGINGS—(Gears, etc.)

Baker Drop Forge Company	Jackson, Mich.
Crescent Drop Forge Company	Hulton, Pa.
L. L. Driggs & Company	New York, N. Y.
Driggs Seabury Ordnance Corporation	Sharon, Pa.
Park Drop Forge Company	Cleveland, Ohio
Transue-Williams Company	Alliance, Ohio
Warner Gear Company	Muncie, Ind.
J. H. Williams & Company	Brooklyn, N. Y.
Wyman-Gordon Company	Worcester, Mass.

VANADIUM AUTOMOBILE CYLINDERS

Capitol Foundry Company	Hartford, Conn.
Du Bois Foundry Company	Cold Spring, N. Y.
Manufacturers Foundry Company	Waterbury, Conn.
Waterbury Castings Company	Waterbury, Conn.

VANADIUM MISCELLANEOUS SHAPES

Bethlehem Steel Company	South Bethlehem, Pa.
Carnegie Steel Company	Pittsburgh, Pa.
Colonial Steel Company	Pittsburgh, Pa.
Crucible Steel Company of America	Pittsburgh, Pa.
Firth-Sterling Steel Company	McKeesport, Pa.
Halcomb Steel Company	Syracuse, N. Y.
Midvale Steel Company	Philadelphia, Pa.
United Steel Company	Canton, Ohio
Vanadium Alloys Steel Company	Latrobe, Pa.
Vulcan Crucible Steel Company	Aliquippa, Pa.

SPRINGS—(Automobile)

Canton Spring & Axle Company	Canton, Ohio
Detroit Steel Products Company	Detroit, Mich.
Hess Pontiac Spring & Axle Company	Pontiac, Mich.
Perfection Spring Company	Cleveland, Ohio
William & Harvey Rowland	Philadelphia, Pa.

SPRINGS—(Locomotive and Large Spiral)

Crucible Steel Company of America	Pittsburgh, Pa.
Pittsburg Spring & Steel Company	Pittsburgh, Pa.
Railway Steel Spring Company	New York, N. Y.
Union Spring Company	Pittsburgh, Pa.

SPRINGS—(Small Spiral, etc.)

American Steel & Wire Company	Pittsburgh, Pa.
Dunbar Brothers	Bristol, Conn.
Gibson Spring Company	Chicago, Ill.
Miller & Van Winkle	New York, N. Y.
Morgan Spring Company	Worcester, Mass.
Raymond Manufacturing Company	Corry, Pa.

TROPENAS CAST STEEL

Brylgon Steel Casting Company	Newcastle, Del.
Falk Steel Casting Company	Milwaukee, Wis.
Reading Steel Casting Company	Reading, Pa.

TUBING—(Welded and Seamless)

National Tube Company	Pittsburgh, Pa.
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